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MICROWAVE PREHEATING OF NATURAL RUBBER

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Preheating of natural rubber using microwave power was investigated with samples supplied by a major Ontario rubber company. Based on the experimental results, microwave power can heat a block of natural rubber approximately nine times faster than conventionally achievable. Equipment size needed to temper the rubber was estimated. Due to the size differences between laboratory and actual products, a full-scale demonstration is recommended to establish the required heating for the production-sized rubber bales.

INTRODUCTION

Through a referral from Raytheon Company, a manufacturer of microwave components, a major rubber company contacted Ontario Hydro Research to investigate microwave preheating of natural rubber.

Natural rubber is the raw material used for making automotive tires. Before the natural rubber is shredded and processed in a mixer, it must be preheated to about 40°C. This preheating of natural rubber using conventional heating is a relatively time consuming process and is inefficient in terms of energy use. Preheating of rubber represents one of the slowest processes in this manufacturing industry, and one which the corporation is interested in improving. At the client's request microwave preheating of natural rubber samples was conducted to determine its effect on process speed. The results were compared with those from conventional heating tests.

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PROCESS DESCRIPTION

In the plant under consideration, natural rubber is processed in bales of about 0.9 m x 1.5 m x 1.1 m in dimension and weighing approximately one metric tonne. Each of these bales consists of smaller blocks (30 cm x 100 cm x 20 cm) which are stacked together to form a large bale. Each of the smaller blocks is wrapped in polyethylene film to reduce moisture gain. The temperature of the rubber samples can vary depending on the season, and can be as low as -10°C in the winter. Before the rubber bales are shredded in a Banbury mixer, they must be heated to about 40°C. These bales are commonly placed in hot rooms (about 50°C) where they reach the required temperature through conductive and convective heat transfer. This process normally takes about four days but may take as long as one week in the winter. It represents one of the slowest processes in tire manufacturing and creates a bottleneck in process flow. In addition, the existing hot rooms are quite old and will soon require upgrading at considerable expense. A literature search and discussions with manufacturers of microwave equipment indicated that similar applications have been examined. Some manufacturers are apparently using this technology although, little published data is available on the actual processes.

SAMPLE DESCRIPTION

In order to perform the laboratory tests, samples of natural rubber were obtained from the rubber company. The samples were about 15 cm x 15 cm x 15 cm in dimension and greenish-dark brown in colour with a relatively strong ammonia odour. The specific gravity of natural rubber is 0.9.

TEST PROCEDURE

Samples of natural rubber were heated from -10°C to 40°C in an industrial microwave oven at 2450 MHz using different output powers, and in a conventional electric oven with a steady oven temperature of 49°C. The temperature of microwave-heated samples was monitored at varying depths using a fibre optic measuring device. In addition to the temperature measurements, the energy consumption for both microwave and convection ovens and incident and reflected microwave powers were recorded. The results from the microwave tests were compared to those of the conventional oven tests.

TEST RESULTS

Table 1 shows a summary of the rubber preheating tests for both microwave and conventional ovens. The temperature readings in the table were taken from the centre of the rubber samples.

TABLE 1

TEST RESULTS PREHEATING OF RUBBER

	Starting Temp (°C)	Final Temp (°C)	Elapsed Time (min)
Microwave (1000 Watts)	-14	40	16
Microwave (500 Watts)	-16	40	56
Conventional	-7.4	40	525

Figure 1 graphically illustrates the heating effects of the microwave versus the conventional oven.

DISCUSSION OF RESULTS

From Figure 1, it can be seen that conventional heating required almost 9 hours for the internal temperature of the rubber to reach 40°C, whereas microwave heating took about 1 hour at 500 W output power. This difference can be attributed to the difference in heating mechanisms.

The conventional heating of rubber and other materials relies on contact with either air or some fluid on the outer surface of the product. The transfer of heat from the outer skin layer to the inside of the product is a function of its thermal conductivity.

The heating mechanism involving microwaves, is quite different. In theory, microwave power can heat a product volumetrically and achieve an even temperature distribution through its cross section in a relatively short time. However, in practice, most products are not homogeneous and therefore, some areas of the product may heat up at different rates. This is strongly dependent on the heating ability of the individual material. In this respect some care is needed to ensure even heating with microwaves. This involves adjusting the microwave power output level and the duration. For example, using 1000 W of microwave output power, the internal core temperature of a rubber sample was heated to 40°C in about 16 min, but the final cross section temperatures ranged from 40°C to 107°C. By reducing the output

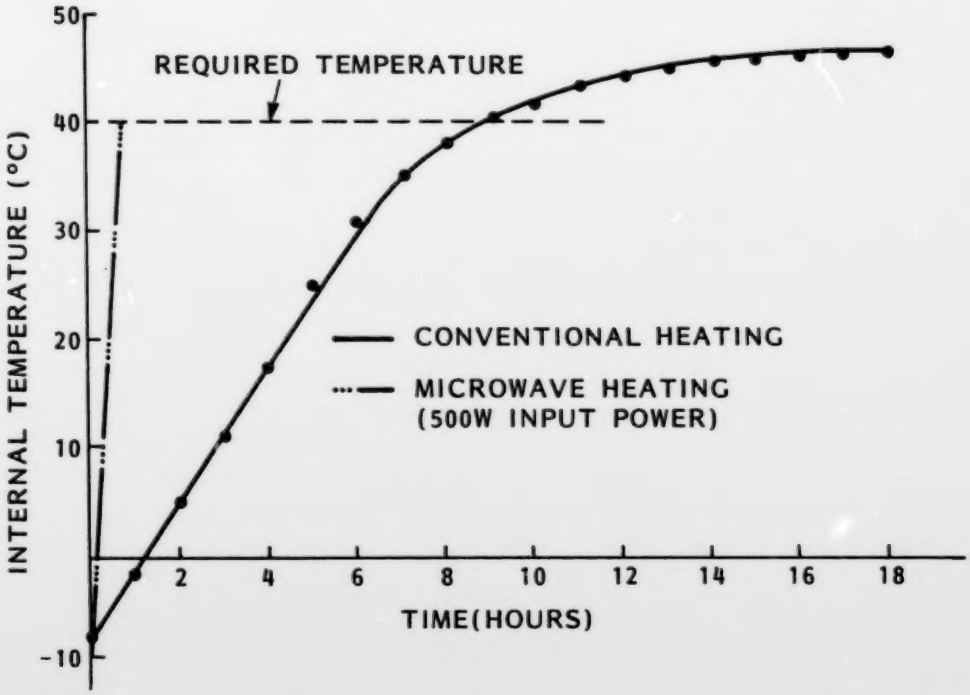

FIGURE 1

PREHEATING OF NATURAL RUBBER
MICROWAVE VS CONVENTIONAL HEATING

power level to 500 W and increasing the duration of heating to about 1 hour, more uniform heating was achieved. In this case, the final cross section temperatures ranged from 38°C to 48°C.

It is apparent that microwave heating can be used to reduce the process time for preheating small samples of rubber. Additional tests are required to assess the effect of microwave power on the larger rubber bales. Part of this question can be answered by calculating the penetration depth of microwaves in natural rubber. This quantity helps to determine the suitability of a product for microwave heating. Calculations show that the penetration depth for natural rubber at 2450 MHz is approximately 2 m, which indicates that suitably sized microwave equipment will provide the necessary penetration of the larger rubber bales.

SIZING OF MICROWAVE UNIT

It is estimated that a 33-kW microwave power unit is needed to process 1000 kg/h of natural rubber (see Appendix for calculations). The calculation does not indicate the effect that the larger microwave system could have on production sizes. A demonstration with full-sized product is required to optimize power application and pulsing time. This demonstration might be best conducted in the plant with suitable monitoring of process time and energy use.

CONCLUSIONS

1. A microwave (at 500 W output power) oven is nine times faster than a conventional oven in heating blocks of natural rubber.

2. Doubling the microwave output power level led to a decrease in process time, however, nonuniform heating resulted.

3. The microwave heating mechanism of production-sized rubber bales can only be established through actual physical testing.

RECOMMENDATION

It is recommended that a full-scale demonstration be conducted to determine the effect of microwave heating on production-sized rubber bales.

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APPENDIX

SIZING OF MICROWAVE UNIT

The following section illustrates the steps required to approximate the size of microwave equipment for this application.

a. Theoretical energy = Q = m x Cp x (T_2 - T_1) needed to heat from T_1 to T_2

where T_2 is the final temperature (°C)
T_1 is the initial temperature (°C)
Cp is the specific heat (kJ/kg°C)
m is the mass of the sample (kg)

b. Time required to heat a sample from T_1 to T_2 using a microwave oven is shown below:

$$t = \frac{Q}{H(1-\rho^2)} \times \frac{wh}{3600\ J}$$

where t is the time required (h)
H is the output of the microwave unit (kW)
ρ is the reflection coefficient (dimensionless)

ρ can be measured easily by experimentation through the following relationship:

$$\rho^2 = \frac{\text{reflected power}}{\text{incident power}}$$

The above quantity is also related to voltage standing wave ratio (VSWR) through the following equation:

$$VSWR = \frac{1 + \rho}{1 - \rho}$$

For sizing a microwave system, a sample calculation for preheating rubber is included. Through laboratory evaluation, the ratio of reflected power to the incident power was found to be about 0.2 (ie $\rho^2 = 0.2$). The specific heat of natural rubber is 0.45 Btu/lb°F or 1885 J/kg°C. In order to heat 1000 kg of natural rubber from -10°C to 40°C in one hour, the size of the microwave oven required is:

$$H = \frac{Q}{t(1-\rho^2)} \times \frac{wh}{3600\ J} = \frac{1000\ kg \times 1.885\ kJ/kg°C \times 50°C}{1\ h \times (1-0.2)} \times \frac{wh}{3600\ J}$$

$$= 32.7\ kW.$$

The above calculation shows that about 33 kW of microwave power is needed to heat 1000 kg of natural rubber in one hour. This calculation does not indicate how the material will actually behave with microwave heating. The actual heating mechanism is quite complex and not easily predicted through calculation or computer simulation due to the non-homogeneity of the actual product. It is only through experimentation that the optimum power and the proper pulsing time (ie, power on and power off cycles) can be determined.